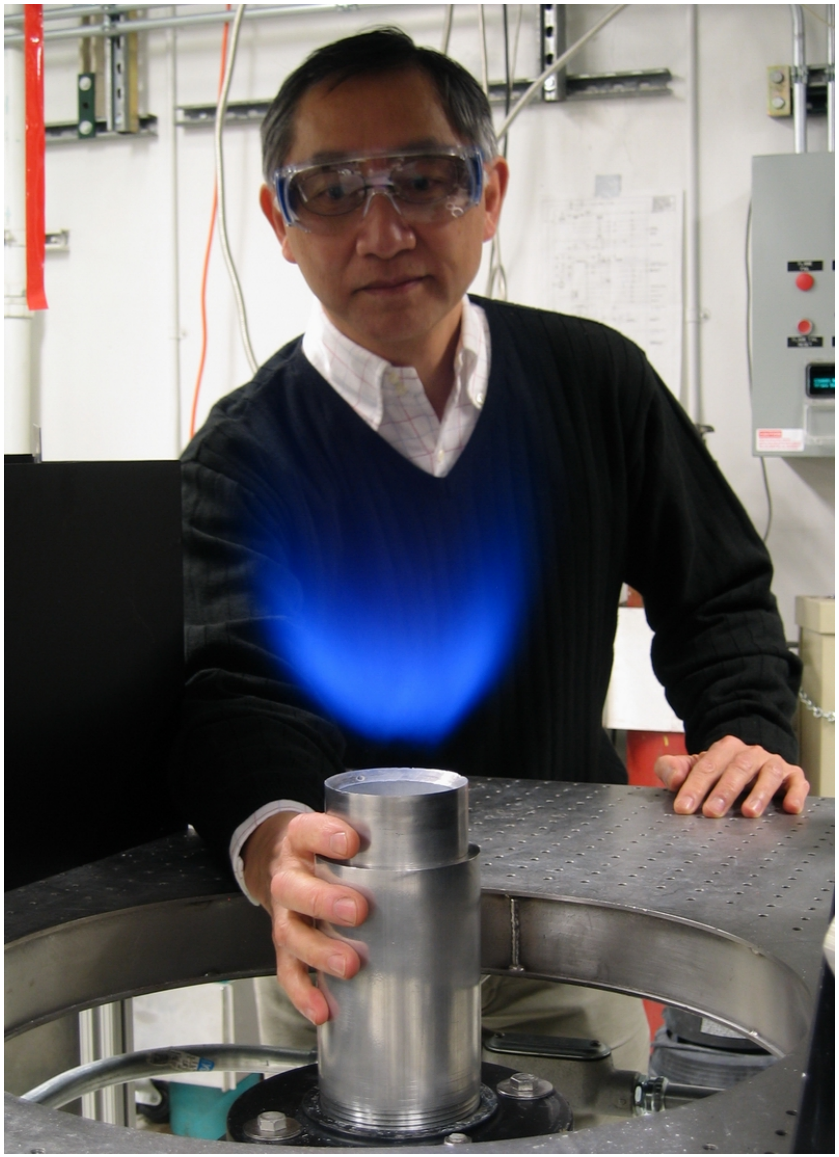
Near Zero Emissions Low-Swirl Combustion for Heating and Power

Robert K. Cheng
Leader, Combustion Technologies Group
Environmental Energy Technologies Div.
Lawrence Berkeley National Laboratory
Berkeley, CA

http://eetd.lbl.gov/aet/combustion/LSC-Info/

What's Unique About Low-swirl Combustion?

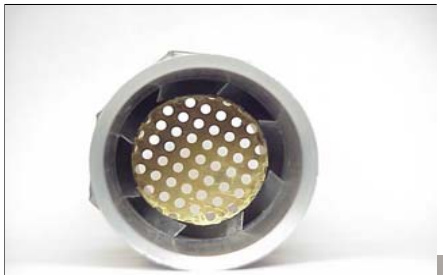


- **LSC is a simple, yet sophisticated way to burn gaseous fuels (hydrocarbons & hydrogen) efficiently with very low NO_x emissions by a lower cost and durable burner**

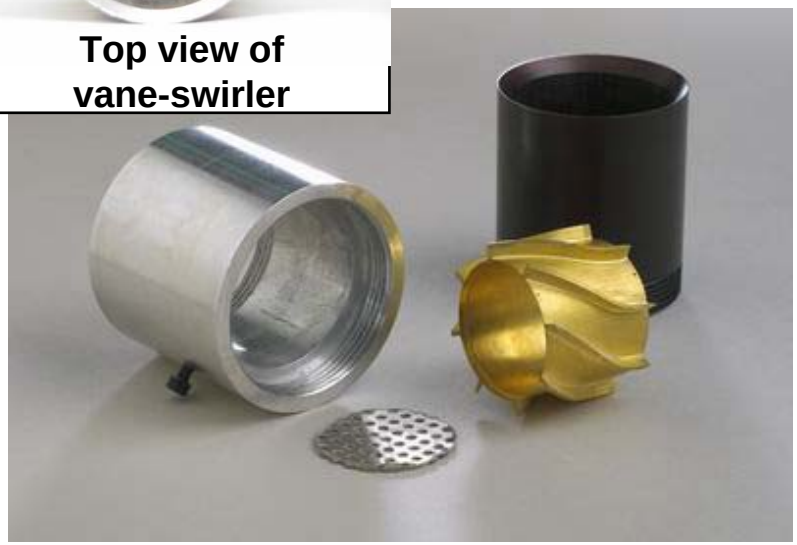
Low-Swirl Combustion (LSC)

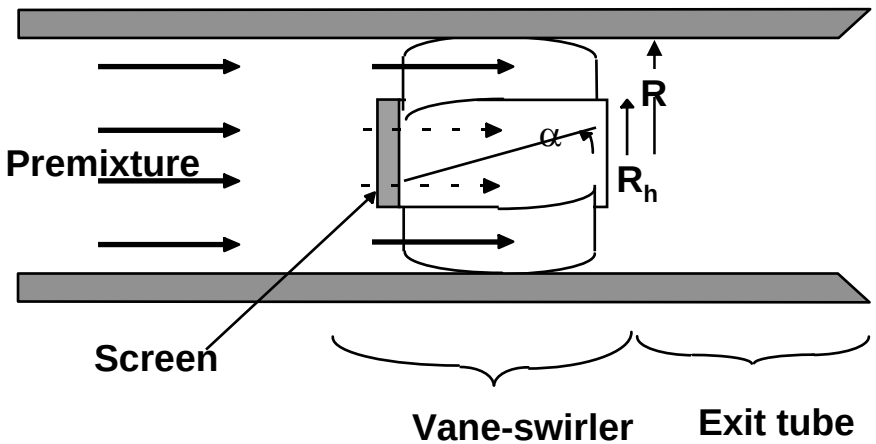
- **LSC is a novel aerodynamic combustion method conceived at LBNL**
  - **Radical approach**
    - **Operating principle defies current common practice**
    - **Adopted by researchers world-wide for fundamental studies**
  - **Technology transfer**
    - **LSC supports robust lean flames with near-zero emissions of NO_x and CO**
    - **2 US patents**
      - **Flame stabilization principle**
      - **Vane-swirler design**
    - **Basic knowledge facilitates development of scaling and engineering rules and practical implementation**

Special Features



Top view of vane-swirler

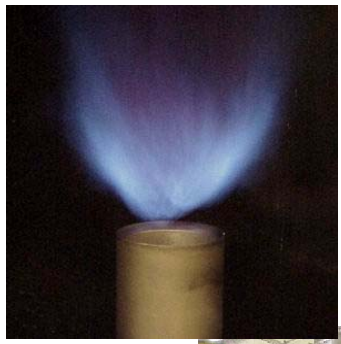


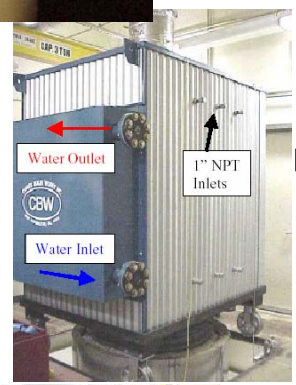


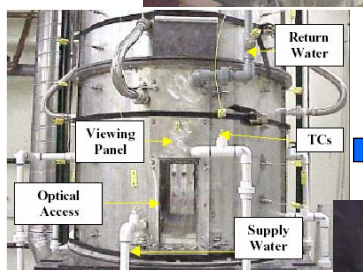
- "Floating" flame
  - Burner does not overheat
- Simple & low cost design
  - Ease of manufacturing
  - Conventional materials
- Adaptable
  - Wide operating conditions
  - Fuel-flexible (all gaseous fuels)
  - Scalable (7 kW to 22 MW)
- High performance
  - Near-zero emissions
  - High turndown
  - Quick startup and shutdown

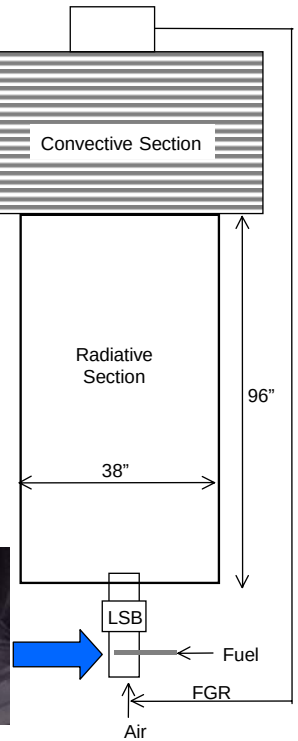
LSC for Industrial Heating

- **Technology transfer began in 1994**
  - **Supported by DOE Office of Science Laboratory Technology Research**
  - **First practical LSB designed for domestic water heaters of 50 kW**
- **DOE-EERE supported development for industrial applications**
  - **Scaled to large boilers with or without flue gas recirculation**
    - **Demonstrated ultra-low emissions operation in boiler systems**
  - **Further development for direct heat applications**



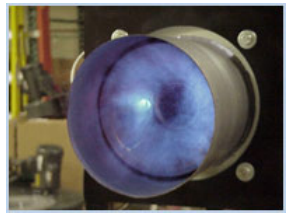


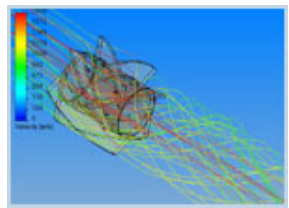


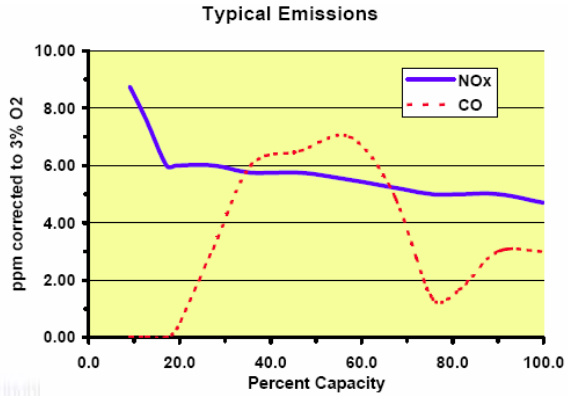


Maxon Corp. Has Two Lines of LSC Products

- Maxon licensed LSC for industrial heating, baking and drying
- "Achieved industry best emissions without sacrificing cost or performance"
  - 4-7 ppm NO_x (@3%O_2) guaranteed
- M-PAKT burners (0.5 – 3.5 MMBtu/hr) available since 9/03
  - Fuel flexible with natural gas, propane and butane
  - 10:1 turndown without pilot assistance
  - Hundred of units installed
  - Improve product quality (paint curing & food processing)
  - 1st unit operating continuously since 2/02
- OPTIMA SLS gas/liquid dual-fuel burners (12 - 50 MMBtu/hr) introduced in 2006
  - 8", 10, 12" and 16" burner diameters
  - enhanced 13:1 turndown
  - backup liquid fuel firing
  - Two prototypes installed & several units in production





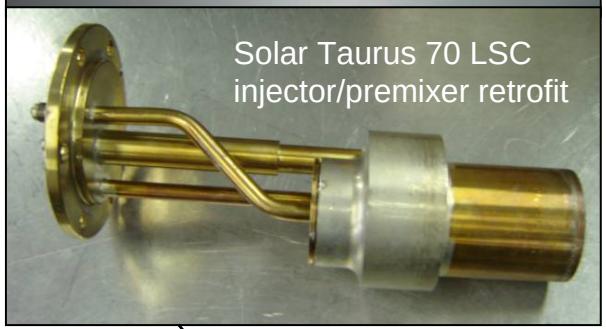


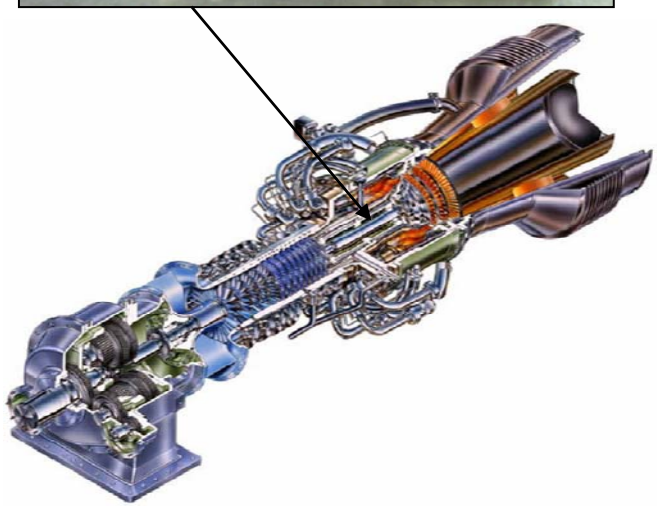
SLS™
shear layer stabilization

Development for Gas Turbines

- **DOE Office of Electricity supporting the adaptation of low-swirl combustion to microturbines and megawatt-size turbines that utilize natural gas and other renewable and on-site generation fuels**
- **DOE Fossil Energy supporting development of low-swirl combustion as an enabling technology for FutureGen turbines in IGCC power plants utilizing high H_2 fuels**
  - **Seek OEMs and vendors as technical advisors and solicit comments and guidance on**
    - **Opportunities and risks of LSC for utility and H_2 turbines**
    - **Scale-up and adaptation targets and approaches**
    - **Identifying combustor and system integration issues**
    - **Developing and steering R&D plan that leads to concept demonstration**
    - **Forming partnerships to develop engine hardware**

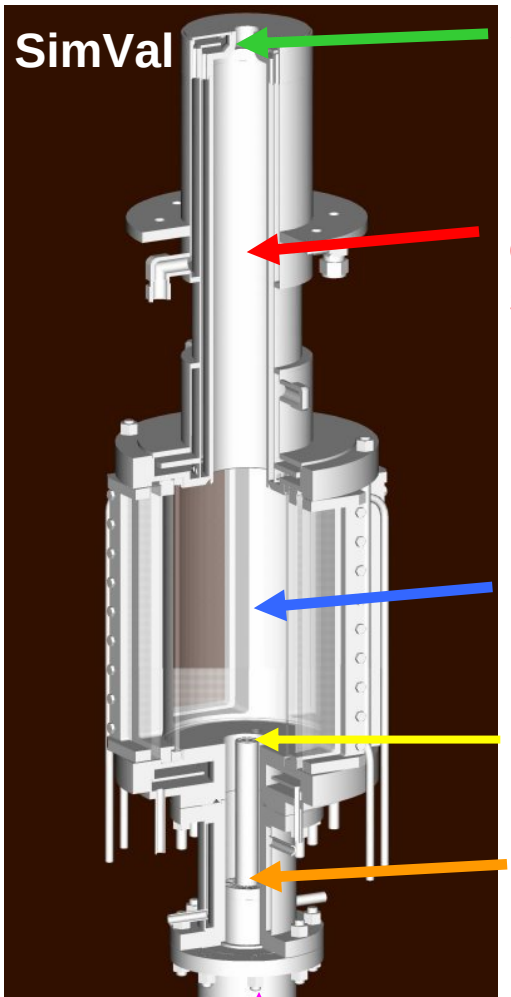
Low Swirl Injector for Solar Turbine T70





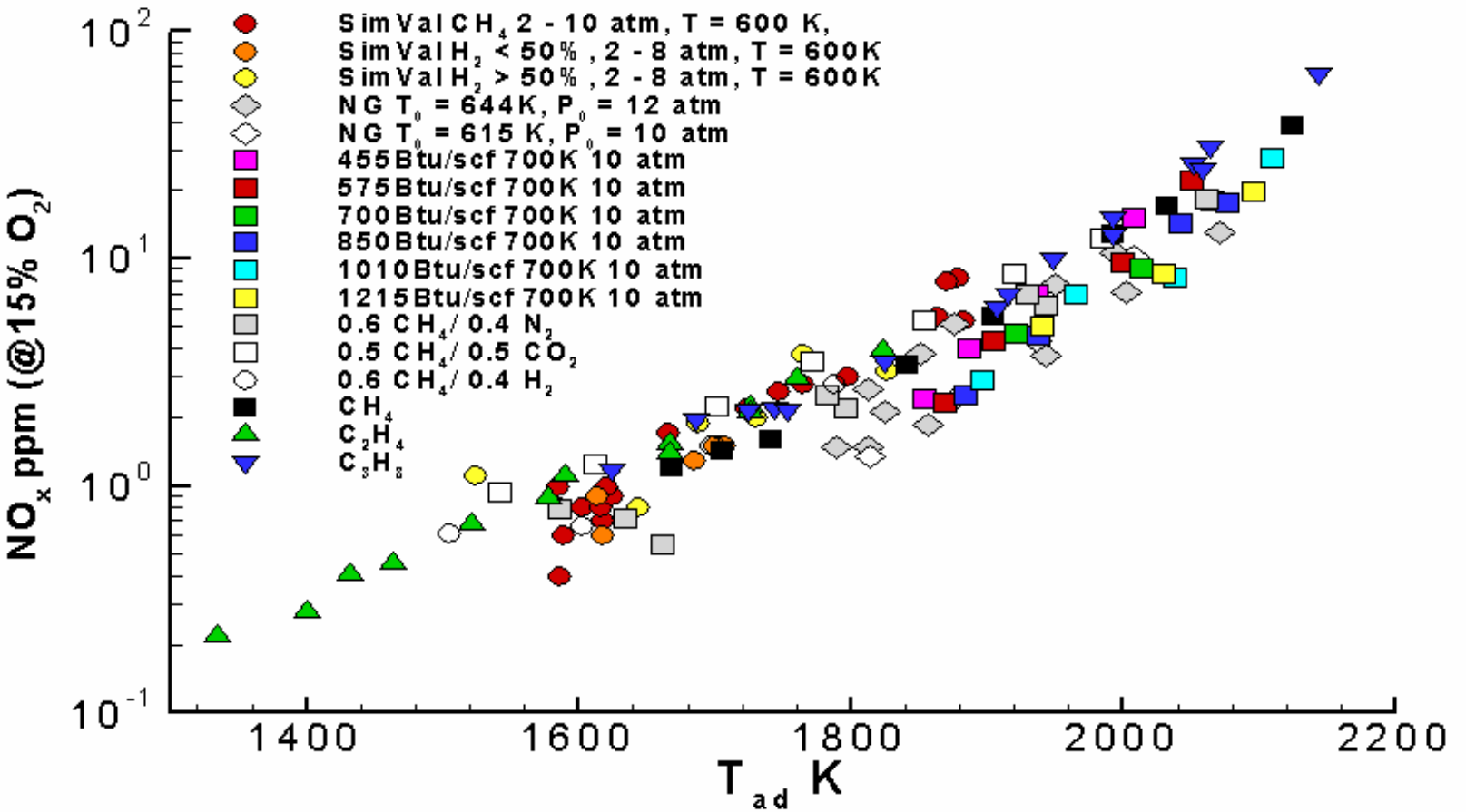
- **Project metrics**
  - **< 5 ppm NO_x (@ 15% O_2)**
  - **Transition to back-up fuels**
  - **Durable for at least 8000 hours**
  - **No more than 10% cost add-on**
  - **No negative impacts on gas turbine performance**
- **Developed "drop-in" retrofit for 7.7 MW Taurus 70 engine**
  - **Simple scalable design built from existing parts**
  - **No special requirements for materials and controls**
  - **Demonstrated in-engine 5 ppm NO_x**
  - **Demonstrated fuel-flexible capability**
  - **Potential for efficiency improvement**
- **Feature article in Gas Turbine World Vol. 36 No. 6 Nov. – Dec. 2006**
- **R&D 100 Award winner 2007**

LSI Fired with Pure H_2 at simulated gas turbine conditions



- **LSI evaluated in SimVal facility at National Energy Technology Lab. (NETL) in Morgantown WV**
  - **Baseline data for natural gas similar to Solar LSI**
  - **Demonstrated LSI operability with pure H_2 at $500 < T < 600K$, $2 < P < 8$ atm**
  - **NO_x emissions from H_2 and natural gas correlate with flame temperature**
- **Analytical model captures the governing flame/flow interaction process in LSI**
  - **Changes in flame position with increasing H_2**
  - **Verification of its validity at turbine conditions will provides a very useful tool for hardware development**

Flame Temperature Dictates LSI NO_x Emissions Regardless of Fuel Type



Laboratory Studies Show LSI Amenable to Burning Pure H_2

- **Dominant flame/flow coupling processes of H_2 and hydrocarbon flames are the same**
  - **Effects due to high diffusivity are impediments to open flame laboratory studies and can be addressed by engineering means**
- **Higher H_2 flame speed correlation accommodated by a small reduction of the swirl number**
- **Demonstrate the viability of the analytical model for H_2 LSI design**
- **Encouraging results useful for guiding the development of H_2 LSI prototype for sub-scale and full scale demonstration at FutureGen**